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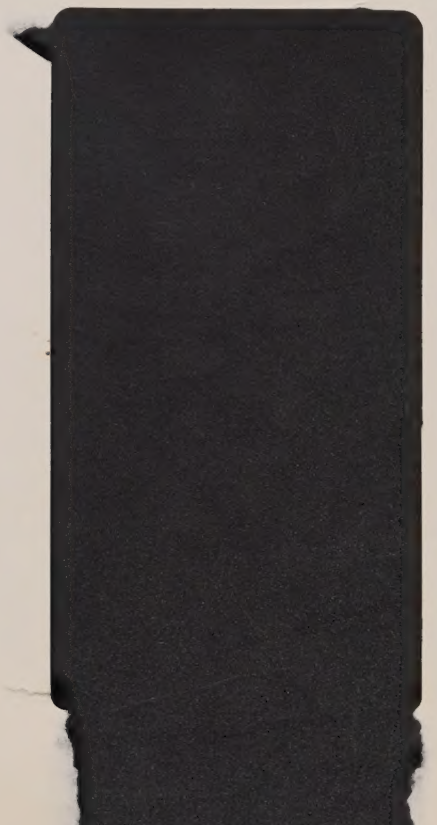
INSTRUCTION MANUAL

MODEL 149

MILLI-MICROVOLTMETER

FEC

KEITHLEY INSTRUMENTS



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SECTION I - INTRODUCTION

The Model 149 milli-microvoltmeter is a stable, versatile instrument for measuring extremely low level DC signals. It functions as a voltmeter from 100 millimicrovolts to 100 millivolts full scale. It also operates as a DC amplifier with gains up to 10^8 for driving recorders.

The very low noise level of the Model 149, together with its long term stability make it ideal for many measurements requiring extreme power sensitivity.

Typical applications include measuring the output from strain gages, thermopiles, thermocouples, bolometers, phototubes, ionization chambers, scintillation counters, and barrier layer cells. Other applications are found in cell studies, measurement of electrochemical potentials, electrolytic corrosion studies, molecular weight analysis and Hall effect studies.

In addition to its use as a direct indicator of minute potentials and currents, the Model 149 may also be used as a null detector in Wheatstone or Mueller bridges.

An important feature of the instrument is zero suppression up to 100 times full scale, in place of the usual more limited meter zero. This permits measurements of small signals in the presence of large thermal EMF's or other masking DC signals.

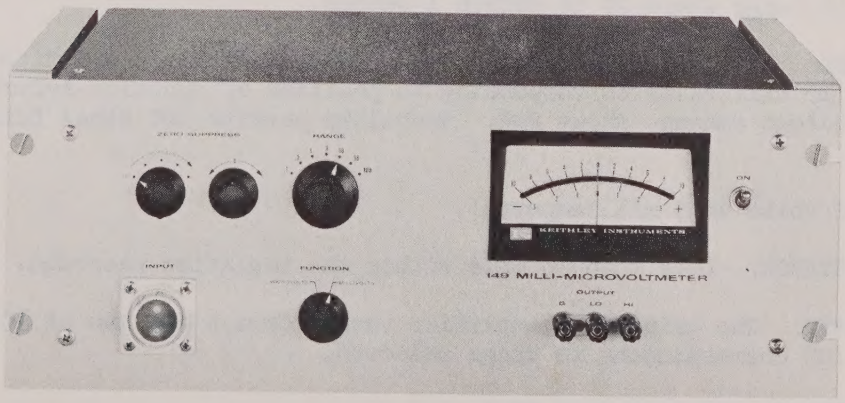


FIGURE 1. Keithley Model 149 Milli-microvoltmeter shown with end frames for bench use.

RANGES: 13 overlapping ranges in 1x and 3x steps from 0.1 microvolt to 100 millivolts on a zero-center meter.

ACCURACY: 2% of full scale on all ranges.

STABILITY: After one-hour warmup within 0.01 microvolt per hour or 0.03 microvolt in any 8-hour period with relatively constant ambient temperatures. Drift is non-cumulative and will not exceed one microvolt during the life of the instrument with source resistances of less than 10 k ohms. If high source resistances are used, an additional drift should be added to the specification. This drift is equal to $\pm 2 \times 10^{-5}$ R microvolts per 8 hours where R is the source resistance in ohms.

NOISE: Input shorted noise is less than 3×10^{-9} volt peak-to-peak (6×10^{-10} volt rms). At various source resistances the peak-to-peak noise in microvolts is given by $E = 6.5 \times 10^{-4} (R + 10)^{\frac{1}{2}}$, since the input noise resistance is added to R, the source resistance in ohms.

INPUT RESISTANCE, MAXIMUM SOURCE RESISTANCE

Range, Microvolts	Input Resistance, Ohms	Maximum Source Resistance, Ohms
0.1	10 k	100
0.3	30 k	300
1.0	100 k	1 k
3.0	300 k	3 k
10.0	1 megohm	10 k
30.0	3 megohms	30 k
100.0 and above	10 megohms	100 k

RESPONSE SPEED: (10 to 90% of full scale) with maximum source resistance, less than 1 second except on 0.1-microvolt range, where it is within 2 seconds. With less than 10% of maximum source resistance, within 0.5 second except on 0.1-microvolt range where it is within 1 second.

ZERO SUPPRESS: Up to 100 times full scale. Ranges of 1 to 1000 microvolts and 0.01 to 10 millivolts corresponding to position of function switch. Accuracy of buckout ranges, about 20%. Stability permits 100 times full scale suppression.

OUTPUT: ± 10 volts at 5 milliamperes.

OUTPUT RESISTANCE: Less than 10 ohms within the amplifier passband.

AMPLIFIER GAIN: The gain as an amplifier varies from a maximum of 10^8 to a minimum of 100 corresponding to range selected.

60 CPS REJECTION: Greater than 50:1.

TABLE 1 (Sheet 1). Model 149 Specifications.

INPUT ISOLATION: Negative terminal may be grounded or floating up to plus or minus 400 volts with respect to the case. A link is provided for grounding the negative terminal to the case. Impedance to ground floating is approximately 10^9 ohms in parallel with 0.05 µf.

CONNECTORS: Input: special receptacle. Front Output: binding posts. Rear Output: Amphenol 80 PC2F receptacle.

TUBE COMPLEMENT: one ~~6048~~ 6084, two EF86, two 12AX7, one 12AT7, one 6CM6, one 0A2, one 12B4A, one ~~5641~~ 5651.

POWER: 105-125 volts (or 210-250 volts), 50 watts, 60 cps only; 50 cps models on special order.

ACCESSORIES SUPPLIED: Model 1501 Low Thermal Test Leads; a length of low thermal solder*; mating output connector.

ACCESSORIES AVAILABLE: Model 1502 Low Thermal Connector Pair; Model 1491 End Frames, with mounting hardware and rubber feet.

DIMENSIONS: 7 inches high x 19 inches wide x 13 inches deep.

NET WEIGHT: 24 pounds.

TABLE 1 (Sheet 2). Model 149 Specifications.

* The solder is screwed to the right side of the copper input chassis, located inside the Model 149. Remove the top cover to reach the solder.

SECTION 2 - OPERATION

A. OPERATING CONTROLS

The controls of the Model 149 are simple and conveniently placed. Their functions are as follows:

ON-OFF switch is located to the right of the panel meter.

FUNCTION switch selects the function which is to be used: Millivolts, or microvolts.

RANGE switch selects the full scale multiplier of the function selected by the FUNCTION switch.

ZERO SUPPRESS controls consists of the ZERO RANGE switch which selects the coarse range of suppressing voltage in discreet steps and the ZERO SET potentiometer which gives continuously variable fine control including settings through zero.

B. PRELIMINARY SET-UP

Connect the instrument to the power line. Unless otherwise marked the unit may be used on 117 volt, 60 cps line. To convert to 220-volt operation, refer to the MAINTENANCE section. A three-wire line cord is furnished, which grounds the cabinet. If a three-wire receptacle is not available, use the two-pin adapter furnished, and ground the third lead to an external ground.

Set controls as follows:

Function: Millivolts

Range: 100

Zero Suppress: OFF

Input: Short the input leads together.

C. GENERAL PRECAUTIONS

1. Source Resistance - In Section 1 under the Input Resistance Specification, the maximum source resistance for use with each voltage range is specified. Reasonable operation is possible with source resistance up to ten times greater than those specified, however, the measurement will suffer from a considerable decrease in speed of response, and measuring accuracy. If the instrument is left completely open-circuited, the meter will generally drift off scale on any range.

2. Shielding - Since the instrument operates with a modulator frequency of 120 cps, it is not generally sensitive to 60 cps pick-up unless it is large enough to overload the amplifier. The pickup may be a source of difficulty when using the amplifier with high impedances on the more sensitive voltage ranges. In these cases it is desirable to shield the leads and the sources as completely as possible. In some cases a simple low-pass filter at the input to eliminate frequencies of about 1 cps and above will be helpful. No use is made of an input filter in this instrument since any input series impedance due to the filter will increase the input noise and the thermal drift. When operating above ground, the case of the instrument must be grounded.

3. Determination of Excessive AC Pickup - A terminal attached to the output of the AC amplifier at the point of the demodulator is provided at the rear of the instrument. It is labeled DEMOD. OUTPUT. If an inability to make consistent readings persists, it is possible to check for the presence of excessive pick-up by observing the wave-form at this point. With the input shorted the picture should be approximately as shown in figure 2. If excessive pickup is observed it will look as shown in figure 3. The circuit will operate reasonably well as long as the wave-form does not clip as shown in figure 4. At this point the operation will be erratic.

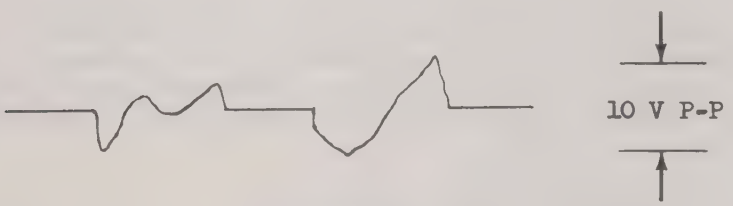


FIGURE 2

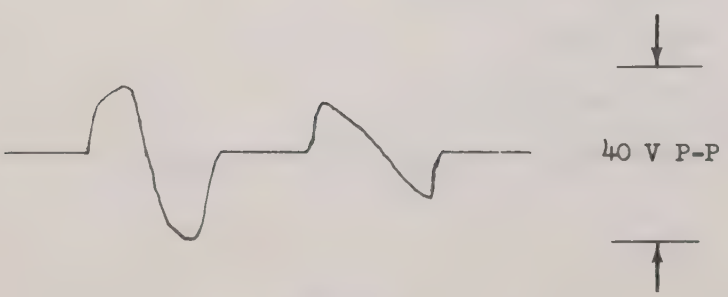


FIGURE 3

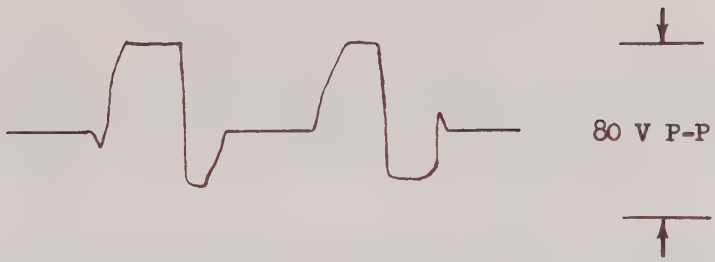


FIGURE 4

4. Thermal EMF - Extreme precautions have been taken in the input circuit to minimize thermal EMF's so the residual EMF is usually less than 0.2 uv. The material used in the input circuit is pure copper. Any other metal will generate a thermocouple potential. Lead solder is particularly troublesome. Where thermal EMF's are a problem, soldering should be done with the cadmium-tin solder supplied with the instrument.

5. Input Noise - The noise at the input is a function of input resistance and is approximately given by

$$E = 1.29 \times 10^{-10} \sqrt{(R+10)}$$

where E is the RMS noise, and R is the source resistance. It is assumed that the bandwidth of the instrument is about 1 cps and the temperature is 80° F. If noise is observed, calculate the theoretical noise and compare results. Also bear in mind that only wire-wound resistors approach the ideal resistor. However, if Evanohm or Manganin resistors are used, a considerable thermal EMF of the resistor material against copper will be observed.

6. Checking the Zero Point - At low levels, spurious EMF's may be generated simply by contact between the input leads and the terminals under test. If possible, always leave the instrument connected and adjust the zero after establishing a zero reference in the apparatus under test. For example, in bridge measurements, disconnect the bridge exciting voltage; or with a phototube, shield the tube from light.

7. Overloads - The current applied to the input circuit should be less than one milliampere dc steady state, 10 milliamperes dc short-term. When the FUNCTION switch is on the MILLIVOLTS position, the off-scale impedance can be as low as 1000 ohms. On the MICROVOLTS position, it may approach one ohm.

D. MEASURING VOLTAGE

1. Direct Voltage Measurements - Place the FUNCTION switch at MILLIVOLTS or MICROVOLTS as necessary for the measurement to be taken. Then turn the RANGE switch to more sensitive ranges until the meter gives a usable deflection.

2. Measuring Voltage Variations - To observe small variations in a large steady signal, first set the FUNCTION and RANGE switches as described in D 1. Then operate the ZERO SUPPRESS switch and potentiometer to reduce the meter deflection to zero. Increase the meter sensitivity with the range

switch. The stability of the suppression voltage is adequate for 100 x full scale suppression. Thus, if a thermocouple is suppling a signal of 10 millivolts to the Model 149 after suppressing the meter deflection to zero, the RANGE may set at 100 microvolts. If the 10 millivolt signal corresponds to a temperature of 250°C then after suppression variations of 2.5°C are seen full-scale.

3. Measuring Differential Voltages - When measurements are to be made in a circuit where the LOW connection is above ground potential, slide OUTPUT LINK from one of its posts. This disconnects the instrument circuit ground from chassis ground. DO NOT attempt to make such measurements where the low side of the circuit being measured is more than 400 volts above external ground potential.

If a recorder is being used with the instrument in this arrangement, the recorder must not be grounded since the low side of the output is no longer being grounded.

E. OTHER APPLICATIONS

1. Null Indicator - The Model 149 makes an extremely sensitive null indicator which may be used in a wheatstone or Mueller Bridge.

If the bridge is arranged so that one terminal of the detector is grounded, the Model 149 may be used as described in D 1. If the detector must be used floating, remove the DISCONNECT LINK at the rear and observe the same precautions as in D 3.

SECTION 3 - CIRCUIT DESCRIPTION

The Model 149 is basically a narrow-band chopper amplifier employing negative feedback to stabilize the gain and increase the input impedance.

A. Input Circuit

Zero Stability: The effect of thermal EMF's generated in the input circuitry is reduced to nearly the vanishing point by the use of only copper in the input circuit. All solder points are made with a low thermal cadmium-tin solder. The chopper and chopper transformer employ copper leads. All switching in the input circuit is accomplished with copper switch. Critical resistors in the input circuit are wound of copper wire. The input connector has solid copper spring-loaded contacts.

The input voltage is applied to the moving arm of a 120 cps mechanical chopper. The feedback voltage is connected to the primary center tap of the input transformer. Thus, the difference voltage is applied first across one half of the primary and then, with phase reversal, to the other half. This full wave error signal is stepped up 90 to 1 by the input transformer and applied to the grid of V1, a 6084 low-noise pentode.

B. AC Amplifier

In parallel with the plate load resistor of V1 is a relatively high Q, 120 cps resonant circuit which narrows the bandwidth and reduces spurious signals.

V2 and V3, EF86 pentodes, further amplify the chopper error signal which is then demodulated synchronously by silicon diodes D1 through D4.

To obtain the 120 cps demodulator driving signal, use is made of the ripple frequency from a bridge rectifier circuit operating from the line voltage. The ripple is used in the primary of the demodulator driver transformer.

C. DC Amplifier

The demodulated signal is applied to the grid of V4. V4, V5, and V6 form the dc amplifier and output cathode follower which add further forward gain to the system and supply output power. Feedback around V4, V5 and V6 multiplies the effective capacitance of demodulator filter capacitor C113 by about 1000. This yields the large equivalent capacitance necessary to smooth the demodulated error signal. Because of the feedback, spurious noise in the dc stages outside the pass band of the whole amplifier are effectively degenerated.

D. Zero Suppression

A low-current ±10 volt supply is derived from the main dc supplies using 10-volt zener diodes. Potentiometer R154 may be set at any voltage from -10 to +10 volts, this voltage is applied through appropriate dropping resistors to the feedback point to achieve zero suppression. The potentiometer is the front panel control marked ZERO SUPPRESS, while switch S3, which determines the portion feedback, is labeled ZERO SUPPRESS, OFF-INCREASE.

E. Other Controls

Two controls are set at the factory and should require only infrequent attention by the user.

R118 is an internal control marked DC AMP BAL. It is used to zero the DC amplifier, i.e., to set the output voltage to zero when the demodulator output is zero. This is not very critical since an unbalance will simply be fed back to the input to produce a small error signal to correct itself. R127 is marked CAL. This is the variable portion of the meter multiplier resistance to allow for meter-to-meter sensitivity differences.

F. Power Supply

A standard half-wave rectifier followed by an R-C filter is used to supply unregulated B+ and B- to the output cathode follower.

The unregulated B- is regulated to -150 volts in V7, OA2, and is used for the negative returns for the dc amplifier.

Unregulated B+ is fed to the plate of V8, 12B4A, the series tube in a 225-volt electronic regulator. The output voltage from this regulator is divided by R510 and R511 and compared to reference tube V9, a 5651. The difference signal is amplified by cascade amplifier V10, a 12AX7, and applied to the grid-cathode circuit of the series tube. This regulated 225 volts supplies B+ directly to the dc amplifier, through a decoupling filter (R176, C110) to the second and third ac amplifier stages, and through another decoupling filter (R103, C104) to the first ac amplifier stage.

Regulated B+ and B- also supply currents to the 10 volt zener diodes which are used for zero suppression. This gives two-stage regulation for these very critical voltages.

Zener Diode D112 regulates the filament voltage of V1 to reduce line transient effects.

SECTION 4 - MAINTENANCE

Except for occasional tube or chopper replacement, very little maintenance is required by the Model 149. Components are operated well below rating and solid state devices are employed where possible to achieve long, trouble-free service.

Certain portions of the input circuit are wired using chopper wire and special cadmium-tin solder. These special joints are painted red. If, for any reason, these joints must be unsoldered or re-soldered, USE ONLY CADMIUM-TIN SOLDER AND A COPPER-TIPPED SOLDERING IRON WHICH HAS NEVER BEEN USED WITH ORDINARY LEAD TIN SOLDER. A small spool of cadmium-tin solder is supplied with each instrument.

What may seem to be circuit failure in the millimicrovoltmeter is quite often found to be an unusual condition in the entire test set-up. Therefore, before trouble-shooting the instrument, check to see whether it operates correctly with:

1. All other circuitry disconnected.
2. Input shorted (with copper leads).
3. Power line voltage and frequency correct.

If the difficulty persists, the following systematic procedure may be employed to determine the fault.

TROUBLE-SHOOTING

Reference is made to the Schematic Diagram 13621D, and the Voltage-Resistance Diagram enclosed at the rear of the manual.

To begin trouble-shooting, short the input terminals, strap G to LO with the link provided, and switch ZERO SUPPRESS, OFF-INCREASE to OFF. A Zero offset of 0.1 to 0.4 microvolt is normal.

EXCESSIVE OUTPUT NOISE (INPUT TERMINALS SHORTED)

Because of the very low signal levels involved, noise in the ac amplifier is difficult to trace except by the substitution method. Most likely noise sources are V1 and the chopper. If noise persists after replacing the chopper, it is being generated in the dc amplifier or power supply. A stage-by-stage search should reveal the source. Very often the noise is generated by R102, low noise metal film resistor. Replace only with the equivalent resistor. Wire-wound resistors tend to introduce inductive pickup.

To replace the chopper, unplug the cap at the top. From the bottom of the Model 149, remove the plate covering the area around the chopper base. Unsolder the chopper leads. Clean out the lead at the input connector; tag the terminal for a correct connection later. Unscrew the chopper mounting screws and lift out the chopper from the top.

Insert the new chopper from the top, putting the wire leads through the holes. For convenience, place the No. 2 lead nearest the Model 149 side as shown in Figure 5. From the bottom, secure the chopper with four No. 4-40 NC-2 screws. Put approximately $3\frac{1}{2}$ in. of teflon tubing over lead No. 2 and $2\frac{1}{4}$ in. over the other two leads.

Solder lead No. 2 to the input connector. Insert a shorting bar into the input connector to push out the leads enough to facilitate working on the connection.

NOTE: Use soldering iron with a new solid copper tip and low-thermal cadmium solder for all solder connections painted red. This solder is supplied with the Model 149. Make sure of good electrical and mechanical connections.

Connect lead No. 1 to the red lead of transformer TR37; connect lead No. 3 to the blue lead of transformer TR37. Make loops at the lead ends, interlock the loops, and solder Do not cross or twist the leads. Slide the tubing over the connections.

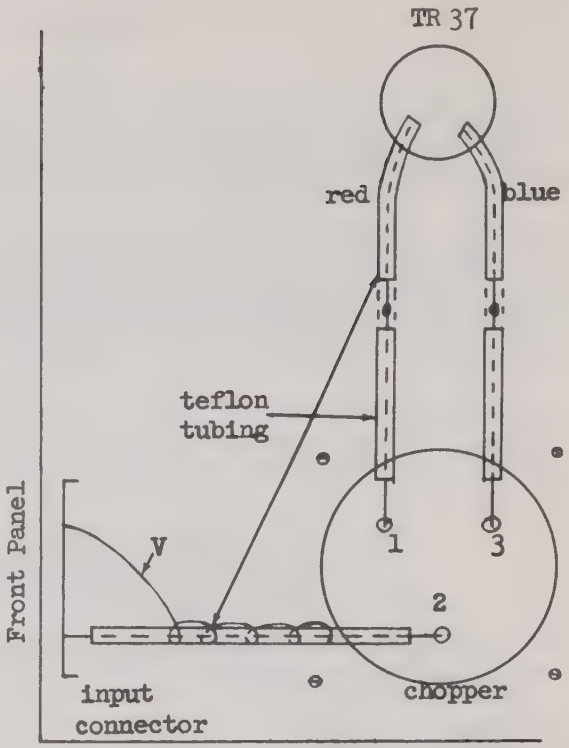


FIGURE 5. Chopper Replacement. View is from the bottom of Model 149.

Twist shield lead V around chopper lead No. 2 as shown in Figure 5. Make sure the end of the shield lead is free of all contact. Replace the plate over the chopper base. Plug in the cap at the top of the chopper.

OUTPUT NOT ZERO (WITHIN 0.5 MICROVOLTS) WITH INPUT TERMINALS SHORTED

Be sure the ZERO SUPPRESS is set to OFF. Short the dc amplifier input grid, pin 7 of V4, to ground. Use the DC AMP BAL control to set the output to zero. The control will become very "scratchy" but the adjustment is possible. If this cannot be done, the dc amplifier or power supply are at fault. If it can be set to zero, the trouble may be in the ac amplifier or demodulator circuit.

a. Power Supply - B+ should be about +225 on pin 1 of V8, and B- should be -150 on pins 2, 4 or 7 of V7. If V7 is not firing, correct the fault in the unregulated B-. If +225 is not present, check for unregulated B+ (about 340 volts) at the plate pin 9 of V8. If the unregulated B+ is all right, check the tube pin voltages of V8, V9, and V10 to locate the faulty tube or part.

b. AC Amplifier - Remove the output tube (V6) and clip pin 1 of the output connector to ground. Place the FUNCTION switch on MILLIVOLTS, and turn the ZERO SET and ZERO RANGE controls full clockwise. This puts a large dc error

signal across the chopper and input transformer. Use an oscilloscope to check for the presence of 120 cps at the primary of the input transformers (the two outside terminals on the chopper terminal block). Absence of signal means chopper failure (or much less likely, a shorted or open input transformer). Listen for audible chopper action and check chopper drive, if necessary.

If the 120 cps signal is present, check stage-by-stage throughout the ac amplifier, reducing the input signal as desired by backing off the ZERO RANGE and/or ZERO SET controls, until the failure is discovered.

d. Demodulator Circuit - Check for presence of about 80 volts RMS at the secondary of the demodulator transformer (at the ends of R113 and R114).

The tests outlined above will not suffice to pin-point every fault which may exist. They should, however, lead to the correction of common failures. In the event that troubles cannot be corrected by these means, or the user finds it more expedient, the unit may be returned to the factory for repair and recalibration at a nominal cost.

220-VOLT OPERATION

For 220-volt operation the power transformer primary connections must be changed. The jumpers connecting black and black-white together and blue and blue-white should be removed. The blue and black-white leads should be tied together. Replace the 1.5-ampere fuse (Keithley Part No. FU-8) with a 0.75-ampere fuse (Keithley Part No. FU-14).

SECTION 5. REPLACEABLE PARTS

REPLACEABLE PARTS LIST. The Replaceable Parts List describes the components of the Model 149 Milli-Microvoltmeter and its accessories. The List gives the circuit designation, the part description, a suggested manufacturer and the Keithley Part Number. The name and address of the manufacturers listed in the "Mfg. Code" column is contained in the Code List of Suggested Manufacturers found immediately after the Replaceable Parts List.

In some instances, it is necessary to substitute parts in the instrument you receive. These substitutions do not impair the performance of the instrument. Either the substitute part or the part specified in the Replaceable Parts List may be used for replacement purposes.

HOW TO ORDER PARTS. For parts orders, include the instrument's model and serial numbers, the Keithley part number, the circuit designation and a description of the part. All structural parts and those parts coded for Keithley manufacture (80164) must be ordered from Keithley Instruments, Inc. In ordering a part not listed in the Replaceable Parts List, completely describe the part, its function and its location.

If any part ordered has been replaced by a new or improved part, the new part will be shipped.

Order parts through:

Sales Service Department
Keithley Instruments, Inc.
12415 Euclid Avenue
Cleveland 6, Ohio
Telephone 795-2666, Area Code 216

amp	ampere	M or meg	mega (10^6) or megohms
		Mfg	Manufacturer
CbVar	Carbon Variable	μ	micro (10^{-6})
CerD	Ceramic, disc	MtF	Metal Film
Coml	Commercial	My	Mylar
Comp	Composition		
		Ω	ohm
DCb	Deposited Carbon		
		PMC	Paper, metal cased
ETB	Electrolytic, tubular		
		v	volt
f	farad	Var	Variable
h	henry	w	watt
		WW	Wire-wound
k	kilo (10^3)	WWVar	Wire-wound Variable

TABLE 2. Abbreviations and Symbols.

MODEL 149 REPLACEABLE PARTS LIST

(Refer to 13621D for circuit designations)

CAPACITORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
C101	Not Used				
C102	4.7 μf	10 v	ETB	05397	C71-4.7
C103	0.1 μf	200 v	PMC	14655	C18-.1
C104	20 μf	450 v	ETB	56289	C8-20L
C105	0.1 μf	400 v	My	00656	C30-.1
C106 (60cps)	0.0082 μf	100 v	My	84411	C45-.0082
C107	5 μf	10 v	ETB	05397	C71-4.7
C108	0.01 μf	600 v	CerD	01121	C22-.01
C109	0.1 μf	200 v	PMC	14655	C18-.1
C110	20 μf	450 v	ETB	56289	C8-20L
C111	5 μf	10 v	ETB	05397	C71-4.7
C112	0.1 μf	400 v	My	00656	C30-.1
C113	0.47 μf	200 v	My	00656	C29-.47
C114	0.001 μf	600 v	CerD	72982	C22-.001
C115 (60cps)	0.0047 μf	600 v	CerD	01121	C22-.0047
C115 (50cps)	0.0047 μf	100 v	My	84411	C45-.0047
C116	0.001 μf	600 v	CerD	72982	C22-.001
C117 (60cps)	*0.0047 μf	600 v	CerD	01121	C22-.0047
C117 (50cps)	*0.0047 μf	100 v	My	84411	C45-.0047
C118 (50cps)	0.0122 μf	100 v	My	84411	C45-.0122
C501	20 μf	600 v	ETB	00656	C35-20
C502	20 μf	450 v	ETB	56289	C8-20L
C503	20 μf	600 v	ETB	00656	C35-20
C504	0.01 μf	600 v	CerD	01121	C22-.01
C505	20 μf	450 v	ETB	56289	C8-20L
C506	*0.5 μf	600 v	My	14655	C92-0.5
C507	1000 μf	15 v	ETB	14655	C11-1000
C508	Not Used				
C509	0.1 μf	400 v	My	00656	C30-.1

DIODES

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.
D101	Silicon	Matched Set	80164	14168A
D102	Silicon	Matched Set	80164	14168A
D103	Silicon	Matched Set	80164	14168A
D104	Silicon	Matched Set	80164	14168A
D105	Selenium	PT065	81483	RF-18

*Nominal value, factory adjusted

DIODES (cont'd)

Circuit Desig.	Type	Number	Mfg. Code	Keithley Part No.
D106	Selenium	PT065	81483	RF-18
D107	Selenium	PT065	81483	RF-18
D108	Selenium	PT065	81483	RF-18
D109	Selenium	PT065	81483	RF-18
D110	Selenium	PT065	81483	RF-18
D111	Selenium bridge, full wave	C1B	81483	RF-7
D112	Zener	1N1589	81483	DZ-4
D113	Zener	1N1314	99942	DZ-2
D114	Zener	1N1314	99942	DZ-2

MISCELLANEOUS

Circuit Desig.	Description	Mfg. Code	Keithley Part No.
F1 (115v)	Fuse, quick-acting, 1.5 amp, 3 AG	75915	FU-8
F1 (230v)	Fuse, quick-acting, 0.75 amp, 3 AG	75915	FU-14
--	Fuse holder	75915	FH-3
G1 (60 cps)	Chopper, Frequency Doubling	80164	CV-2
G1 (50 cps)	Chopper, Frequency Doubling	80164	CV-3
J1	Receptacle Assembly, INPUT (Mating plug is Keithley part 13011B)	80164	12450B
J2	Jack, Phone, DEMOD TEST (Mfg. No. 275)	83330	CS-65
J3	Receptacle, Microphone, OUTPUT (Mfg. No. 80 PC2F)	02660	CS-32
--	Plug, Microphone, for Output (Mfg. No. 80 PC2M)	02660	CS-33
--	Binding Posts (2), OUTPUT, black (Mfg. No. DF21BC)	58474	BP-11B
--	Binding Post, OUTPUT, red (Mfg. No. DF21RC)	58474	BP-11R
--	Shorting Link (Mfg. No. 938-L)	24655	BP-6
L1	Choke, 200h	80164	CH-1
M	Meter	80164	ME-14
--	Meter Lamp (Mfg. No. 323)	08804	PL-1
--	Power Cord, 6 feet	80164	CO-2
--	Strain Relief	80164	CC-7
S1	Rotary Switch less components, FUNCTION	80164	SW-109
--	Switch Assembly with components, Function	80164	13728B
--	Skirted Knob, Function Switch	80164	KN-11
S2	Rotary Switch less components, RANGE	80164	SW-96
--	Switch Assembly with components, Range	80164	13727B

MISCELLANEOUS (Cont'd)

Circuit Desig.	Description	Mfg. Code	Keithley Part No.
--	Skirted Knob, Range Switch	80164	KN-10
S3	Rotary Switch less components, ZERO SUPPRESS, Range	80164	SW-58
--	Switch Assembly, Zero Suppress, Range	80164	13726B
--	Skirted Knob, Zero Suppress Range Switch	80164	KN-11
--	Skirted Knob, Zero Suppress Set Potentiometer	80164	KN-17
S4	Toggle Switch, DPDT, ON	04009	SW-14
T1	Transformer, Power	80164	TR-36
T2	Transformer, Filament	80164	TR-26
T3	Transformer, Chopper	80164	TR-37

RESISTORS

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
R101	33 kΩ	10%, ½ w	Comp	01121	R1-33K
R102	2 MΩ	1%, 1 w	Mtf	75042	R44-2M
R103	47 kΩ	10%, ½ w	Comp	44655	R1-47K
R104	1 MΩ	1%, ½ w	DCb	00327	R12-1M
R105	3.3 MΩ	10%, ½ w	Comp	01121	R1-3.3M
R106	1 MΩ	1%, ½ w	DCb	00327	R12-1M
R107	22 kΩ	10%, ½ w	Comp	44655	R1-22K
R108	3.3 MΩ	10%, ½ w	Comp	01121	R1-3.3M
R109	1 MΩ	1%, ½ w	DCb	00327	R12-1M
R110	22 kΩ	10%, ½ w	Comp	44655	R1-22K
R111	1 MΩ	1%, ½ w	DCb	00327	R12-1M
R112	200 kΩ	1%, ½ w	DCb	01661	R12-200K
R113	100 kΩ	1%, ½ w	DCb	00327	R12-100K
R114	100 kΩ	1%, ½ w	DCb	00327	R12-100K
R115	*1 MΩ	1%, ½ w	DCb	00327	R12-1M
R116	470 kΩ	1%, ½ w	DCb	01661	R12-470K
R117	333 kΩ	1%, ½ w	DCb	00327	R12-333K
R118	500 kΩ	10%, 2 w	CbVar	01121	RP5-500K
R119	680 kΩ	1%, ½ w	DCb	01661	R12-680K
R120	3.33 MΩ	1%, ½ w	DCb	00327	R12-3.33M
R121	2.2 MΩ	1%, ½ w	DCb	01661	R12-2.2M
R122	60 kΩ	1%, ½ w	DCb	00327	R12-60K
R123	100 kΩ	1%, ½ w	DCb	00327	R12-100K
R124	1.3 MΩ	1%, ½ w	DCb	01661	R12-1.3M
R125	1 MΩ	1%, ½ w	DCb	00327	R12-1M

*Nominal value, adjusted at factory

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
R126	30 kΩ	5%, 10 w	WW	63743	R5-30K
R127	10 kΩ	10%, 2 w	WWVar	12697	RP9-10K
R128	96 kΩ	1%, ½ w	DCb	00327	R12-96K
R129	1 Ω	1%	WW Special	80164	R18-18-1
NOTE:	R129 and R130 are matched to 1/2%. Order as pair				
R130	1 kΩ	1%	WW Special	80164	R18-18-1K
R131	111 Ω	1%, ½ w	DCb Special	80164	R38-111
R132	10 kΩ	5%	WW Special	80164	R18-19-10K
R133	100 kΩ	1%, ½ w	DCb Special	80164	R38-100K
R134	10 MΩ	1%, ½ w	DCb	01661	R12-10M
R135	3.33 MΩ	1%, ½ w	DCb	00327	R12-3.33M
R136	1 MΩ	1%, ½ w	DCb	00327	R12-1M
R137	333 kΩ	1%, ½ w	DCb	00327	R12-333K
R138	100 kΩ	1%, ½ w	DCb	00327	R12-100K
R139	33.3 kΩ	1%, ½ w	DCb	00327	R12-33.3K
R140	9.9 kΩ	1%, ½ w	DCb	01661	R12-9.9K
R141	470 kΩ	10%, ½ w	Comp	01121	R1-470K
R142	100 kΩ	10%, ½ w	DCb Special	80164	R38-100K
R143	*220 kΩ	10%, ½ w	Comp	01121	R1-220K
R144	*150 kΩ	10%, ½ w	Comp	44655	R1-150K
R145	*150 kΩ	10%, ½ w	Comp	44655	R1-150K
R146	*150 kΩ	10%, ½ w	Comp	44655	R1-150K
R147	22 kΩ	10%, ½ w	Comp	01121	R1-22K
R148	8.2 kΩ	10%, ½ w	Comp	01121	R1-8.2K
R149	2.2 kΩ	10%, ½ w	Comp	44655	R1-2.2K
R150	1 kΩ	1%, ½ w	DCb	00327	R12-1K
R151	1 MΩ	1%, ½ w	DCb	00327	R12-1M
R152	100 kΩ	1%, ½ w	DCb	01661	R12-100K
R153	9 kΩ	1%, ½ w	DCb	00327	R12-9K
R154	10 kΩ	3%, 5 w	WWVar	73138	RP4-10K
R155	30 kΩ	5%, 10 w	WW	63743	R5-30K
R176	10 kΩ	10%, ½ w	Comp	01121	R1-10K
R501	100 Ω	10%, 2 w	Comp	01121	R3-100
R502	100 Ω	10%, 2 w	Comp	01121	R3-100
R503	5 kΩ	5%, 10 w	WW	44655	R5-5K
R504	5 kΩ	5%, 10 w	WW	44655	R5-5K
R505	22 kΩ	10%, 2 w	Comp	44655	R3-22K
R506	10 MΩ	10%, ½ w	Comp	01121	R1-10M
R507	220 kΩ	1%, ½ w	DCb	01661	R12-220K
R508	33 kΩ	10%, ½ w	Comp	01121	R1-33K
R509	33 kΩ	10%, ½ w	Comp	01121	R1-33K
R510	1 MΩ	10%, ½ w	Comp	44655	R1-1M

*Nominal value, adjusted at factory

RESISTORS (Cont'd)

Circuit Desig.	Value	Rating	Type	Mfg. Code	Keithley Part No.
R511	600 kΩ	1%, $\frac{1}{2}$ w	DCb	00327	R12-600K
R512	10 Ω	5%, 10 w	WW	63743	R4A-10

VACUUM TUBES

Circuit Desig.	Number	Mfg. Code	Keithley Part No.
V1	6084	73445	EV-6084/E80F
V2	EF86	73445	EV-EF86/6267
V3	EF86	73445	EV-EF86/6267
V4	12AX7	73445	EV-ECC83/12AX7
V5	12AT7	73445	EV-12AT7
V6	6CM6	00011	EV-6CM6
V7	0A2	86684	EV-0A2
V8	12B4A	85599	EV-12B4A
V9	CK5651	81453	EV-CK5651
V10	12AX7	73445	EV-ECC83/12AX7

MODEL 1491 REPLACEABLE PARTS LIST

Description	No. Required Per Model	Mfg. Code	Keithley Part No.
End Frames	2	80164	13120C
Fastener, Thumbscrew	4	80164	FA-9
Feet, Rubber	4	80164	FE-2
Attaching Parts			
Machine Screw, No. 6-32UNC-2x$\frac{1}{2}$, Rd Hd, Phillips	4	Coml	--
Hex Nut, No. 6-32UNC-2	4	Coml	--
- - - - - - - - - -			
Machine Screw, No. 8-32UNC-2x5/16, Rd Hd, Phillips	4	Coml	--

MODEL 1501 REPLACEABLE PARTS LIST

Description	Mfg. Code	Keithley Part No.
Plug Assembly	80164	13011B
Cable, 48 inches, Vinyl, shielded	86696	SC-5
Alligator Clamps, (2), (Mfg. No. 60C5)	76545	AC-8

MODEL 1502 REPLACEABLE PARTS LIST

Description	Mfg. Code	Keithley Part No.
Plug Assembly	80164	13011B
Cable, 10 feet, Vinyl, shielded	86696	SC-5

CODE LIST OF SUGGESTED MANUFACTURERS

00011 Sylvania Electric Products, Inc.
Electronic Tubes Div.
Buffalo, N. Y.

00327 Welwyn International, Inc.
Cleveland, Ohio

00656 Aerovox Corp.
New Bedford, Mass.

01121 Allen-Bradley Corp.
Milwaukee, Wis.

01661 Wilrite Products, Inc.
Cleveland, Ohio

02660 Amphenol Connector Division
Amphenol-Borg Electronics Corp.
Chicago, Illinois

04009 Arrow-Hart & Hageman Electric Co.
Hartford, Conn.

05397 Kemet Co.
Cleveland, Ohio

08804 General Electric Co.
Lamp Division
Cleveland, Ohio

12697 Clarostat Mfg. Co., Inc.
Dover, N. H.

14655 Cornell-Dubilier Electronics
Div. of Federal Pacific Electric Co.
Newark, N. J.

24655 General Radio Co.
West Concord, Mass.

44655 Ohmite Mfg. Co.
Skokie, Ill.

56289 Sprague Electric Co.
North Adams, Mass.

58474 Superior Electric Co., The
Bristol, Conn.

63743 Ward Leonard Electric Co.
Mount Vernon, N. Y.

72982 Erie Resistor Corp.
Erie, Pa.

73138 Helipot Division
Beckman Instruments, Inc.
Fullerton, Calif.

73445 Amperex Electronic Corp.
Hicksville, N. Y.

75042 International Resistance Co.
Philadelphia, Pa.

75915 Littelfuse, Inc.
Des Plaines, Ill.

76545 Mueller Electric Co.
Cleveland, Ohio

80164 Keithley Instruments, Inc.
Cleveland, Ohio

81453 Raytheon Co.
Industrial Components Div.
Newton, Mass.

81483 International Rectifier Corp.
El Segundo, Calif.

83330 Smith, Herman H., Inc.
Brooklyn, N. Y.

84411 Good-All Electric Mfg. Co.
Ogallala, Nebr.

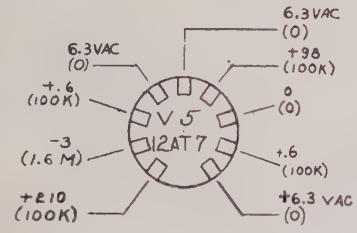
CODE LIST OF SUGGESTED MANUFACTURERS (Cont'd)

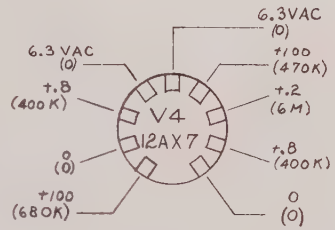
85599 General Electric Co.
Schenectady, New York

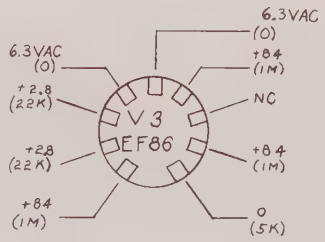
86684 Radio Corp. of America
RCA Electron Tube Div.
Harrison, N. J.

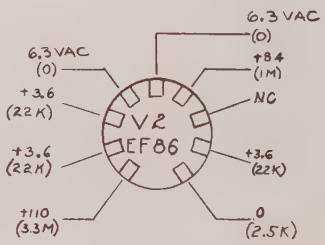
86696 Radix Wire Co.
Cleveland, Ohio

99942 Hoffman Electronics Corp.
Semiconductor Division
El Monte, Calif.









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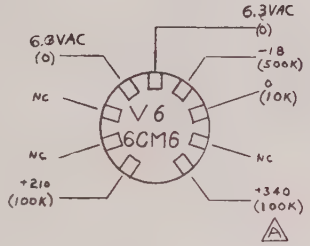
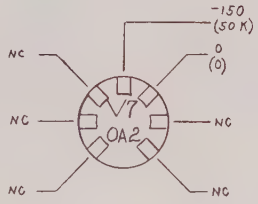
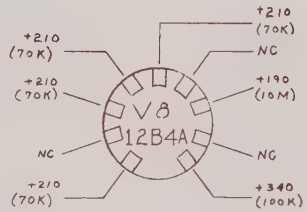
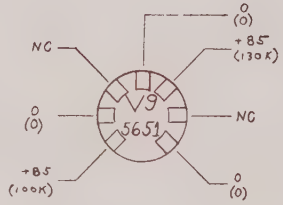
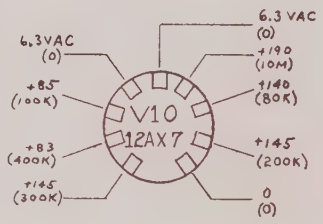








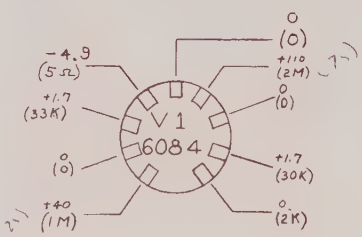


MODEL 149
VOLTAGE AND RESISTANCE CHART

B

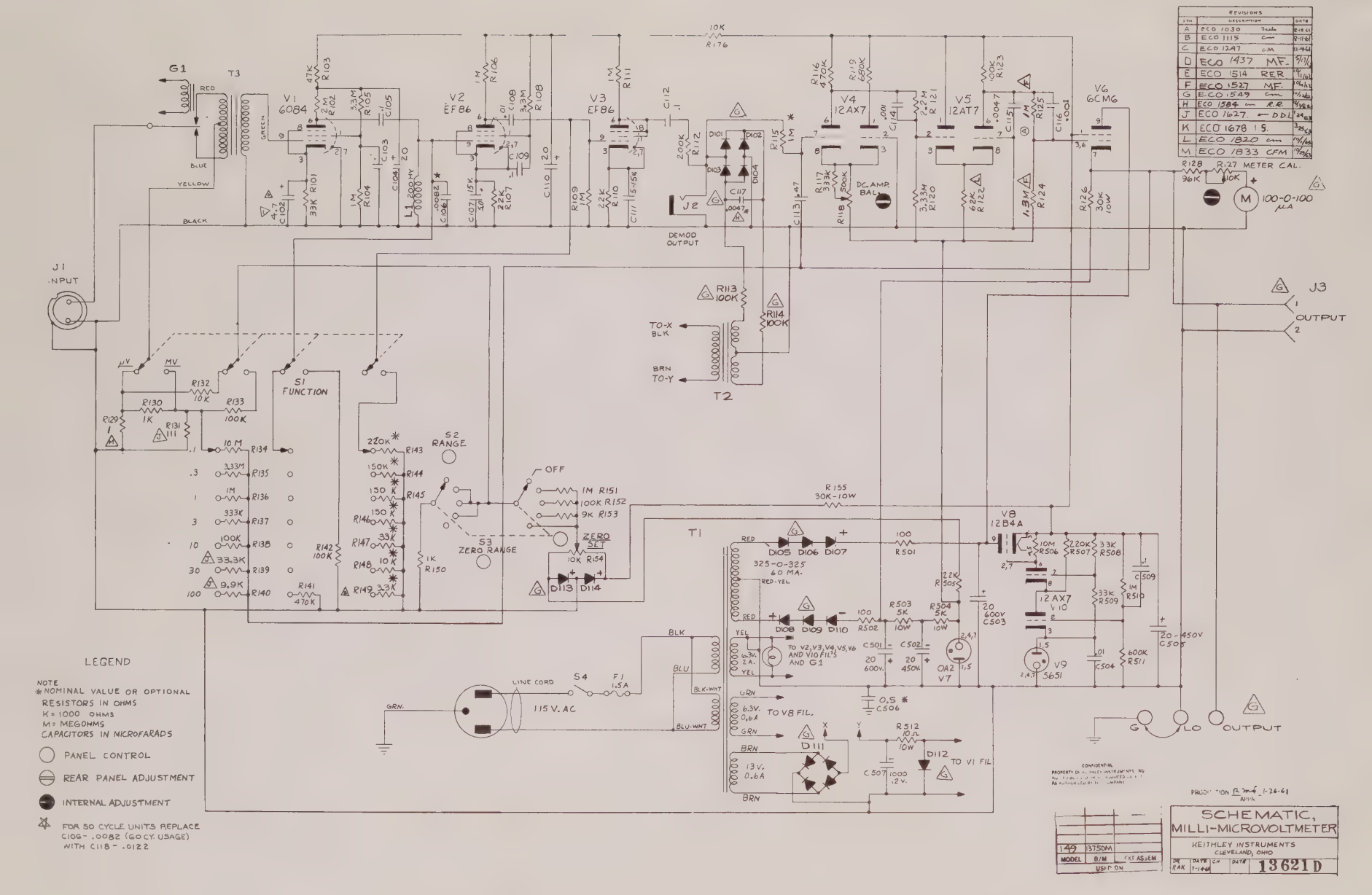
MEASUREMENTS FROM TUBE PIN TO GROUND USING VTVM WITH 100 MEGOHM INPUT RESISTANCE. FUNCTION SWITCH AT MILLIVOLTS, INPUT SHORTED, RANGE SWITCH AT 1000, ZERO SUPPRESS OFF.

ALL READINGS ARE APPROXIMATE:
RESISTANCES ARE GIVEN IN OHMS; K=1000; M=MEGOHMS



B	ECO 1663	
A	PER D.C.N. WAS 500K	5-26-61

KEITHLEY INSTRUMENTS
13745C



LEGEND

NOTE
*NOMINAL VALUE OR OPTIONAL
RESISTORS IN OHMS
K = 1000 OHMS
M = MEGOHMS
CAPACITORS IN MICROFARADS

- PANEL CONTROL
- REAR PANEL ADJUSTMENT
- INTERNAL ADJUSTMENT
- FOR 50 CYCLE UNITS REPLACE C108 - .0082 (60 CY. USAGE) WITH C118 - .0122

REVISIONS		
LTR	DESCRIPTION	DATE
A	ECO 1030	2-18-61
B	ECO 1115	2-11-61
C	ECO 1247	3-14-61
D	ECO 1437 MF.	5/1/61
E	ECO 1514 RER	8/11/61
F	ECO 1527 MF.	9/14/61
G	ECO 1549	9/15/61
H	ECO 1584 RR	9/18/61
J	ECO 1627 DDL	12/8/61
K	ECO 1678	2/23/62
L	ECO 1820	7/16/62
M	ECO 1833 CFM	9/6/62

CONFIDENTIAL
PROPERTY OF KEITHLEY INSTRUMENTS INC. IT MAY NOT BE REPRODUCED OR USED AS AUTHORIZED BY THE COMPANY

PRODUCTION RELEASE 1-26-61

149	3750M	
MODEL	B/M	EXT ASSEM
USED ON		

SCHEMATIC, MILLI-MICROVOLTMETER
KEITHLEY INSTRUMENTS
CLEVELAND, OHIO
DR RAK DATE 7-14-61 CH DATE
13621D

WARRANTY

We warrant each of our products to be free from defects in material and workmanship. Our obligation under this warranty is to repair or replace any instrument or part thereof (except tubes and batteries) which, within a year after shipment, proves defective upon examination. We will pay domestic surface freight costs.

To exercise this warranty, call your local field representative or the plant directly, DDD 216-795-2666. You will be given assistance and shipping instructions.

REPAIRS AND RECALIBRATION

Keithley Instruments maintains a complete repair service and standards laboratory in Cleveland, and has authorized field repair facilities in Los Angeles and Albuquerque.

To insure prompt repair or recalibration service, please contact your local field representative, or the plant directly, before returning the instrument.

Estimates for repairs, normal recalibrations, and calibrations traceable to the National Bureau of Standards are available upon request.

KEITHLEY INSTRUMENTS, INC.
12415 EUCLID AVENUE
CLEVELAND, OHIO 44106